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Polarization Holographic Gratings in Azopolymers for Detecting and Producing Circularly Polarized Light

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13. ABSTRACT (Maximum 200 words)

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Polarization holographic gratings in azopolymers for detecting and producing circularly polarized light.

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Polarization holographic gratings were inscribed in azobenzene side chain polymer films. The polarization gratings were produced using two orthogonally circularly polarized beams and the resulting stable transmission gratings were studied using a low power HeNe laser. The gratings were observed to efficiently separate left and right circularly polarized light from the probe beam and two generate two elliptically polarized beams in the first order diffraction direction.

2. INTRODUCTION

The availability of materials in which optical anisotropy can be photoinduced has led to a number of interesting studies on the recording of polarization holograms[1-3]. These are made by the interference of two beams recorded in the material where the interference pattern is not a variation of intensity but rather a variation in the polarization state of the resultant wave in the material. The local polarization of the light is then recorded in an optically anisotropic material. In the present paper we consider the case when the holographic recording beams are of equal intensity and are orthogonally circularly polarized. One of the interesting properties of the holographic grating produced by these two beams is that it diffracts the left (LCP) and right-hand (RCP) circularly polarized light from a probe beam into two separate directions [4,5]. This can then lead to a simple device that could measure the total polarization state of an input beam over a wide wavelength range. The theory also predict that this grating could be used to produce circularly polarized light of selected handedness again over a wide wave length range. In the present study we consider the production of these holographic gratings in azobenzene side chain polymers .

Azobenzene side chain polymers have been shown to have large, stable birefringence can be optically induced using moderate power argon lasers and short exposure times[6] The recording medium is a thin film (ca. 400 nm thick) which is made by spin coating the polymer which is dissolved in tetrahydrofuran onto a glass substrate. The azobenzene molecules are intrinsically anisotropic but they are initially deposited in random directions making the film amorphous and isotropic. The molecules can be made to change shape and direction by the process of photoisomerization. Upon exposure to linearly polarized light the molecules tend to re-align in a direction that is perpendicular to the polarization direction. This results in a local optical anisotropy that can be detected using a probe which does not cause photoisomerization but which is still sensitive to the local birefringence. The optically induced birefringence in side chain azopolymers is stable over extended periods (years) . therefore the holographic gratings can be components of a polarization measurement system as long as the films are protected against erasure.

3.EXPERIMENT

The holographic polarization grating was produced by the superposition of two orthogonal circularly polarized beams as illustrated below:

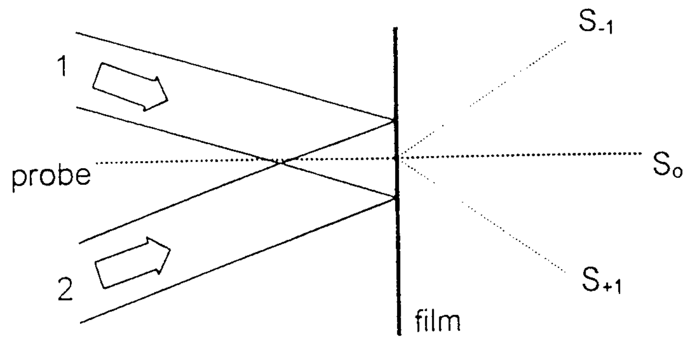

FIGURE 1: Optical set-up

The writing beams , 1 and 2, are from a 50 mW/cm^2 Argon laser at 488 nm and the probe beam is from a 10 μW HeNe laser at 632.8 nm. The film was a side chain azopolymer[5] , pDR1M, which was cast onto a glass substrate. The writing beams are orthogonally circularly polarized to produce the following polarization patterns on the film:

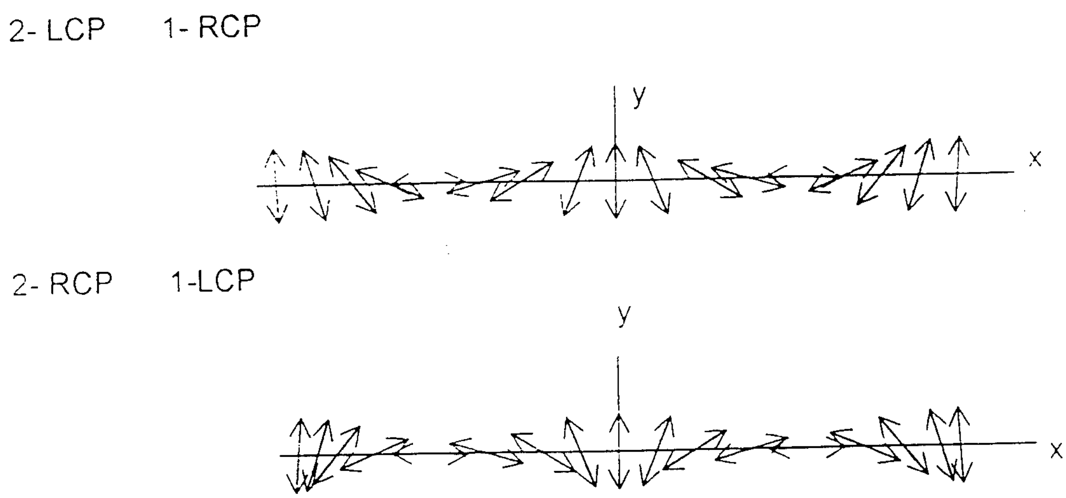

FIGURE 2 : Polarization gratings

We note that the first pattern is a rotation of the first pattern about the x-axis or z-axis(out of the paper). The angle between the writing beams was adjusted to give a grating spacing of about 6 micrometers. The polarization gratings were produced by writing for 100 seconds, which is enough time for the optically induced birefringence to reach saturation in these films. The birefringence was then allowed to relax in the dark for 500 seconds to reach the more stable long term birefringence levels of $\Delta n = 0.06$. The probe beam was then used to obtain the diffraction characteristics of the gratings. The probe beam polarization state was varied using a quarter wave plate and the polarization could be continuously varied from left circular to linear to right circular.

4. RESULTS AND DISCUSSION

The polarization grating can be described by the following transmission Jone 's matrix[7] :

$$[T] = e^{i\varphi_0}\left\{\cos(\Delta\varphi)\begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix} + \sin(\Delta\varphi)\frac{e^{i\delta}}{2}\begin{pmatrix}i & 1\\ 1 & -i\end{pmatrix} + \sin(\Delta\varphi)\frac{e^{-i\delta}}{2}\begin{pmatrix}i & -1\\ -1 & -i\end{pmatrix}\right\}$$

Where φ_0 is the average phase delay through the film. $\Delta\varphi = \pi d\cdot\Delta n/\lambda$ is the anisotropic phase delay due to the birefringence, and $\delta = 2\pi x/\Lambda$ is the phase delay along the grating with spacing Λ. In the above equation the first term in the brackets is the directly transmitted beam, the second term is the beam in the +1 order of diffraction and the third term is the beam in the -1 order of diffraction. One can readily see that in the above case a right circularly polarised beam of light , $\begin{bmatrix}1\\ -i\end{bmatrix}$ would only be diffracted into the -1 order and that the resultant beam would be left circularly polarised. We have investigated this anisotropic diffraction property of the polarization gratings for circularly polarized light and the results are summarised in the following table which gives the direction and polarization state of the diffracted beams.

TABLE1: Diffraction of a circularly polarized probe beam

BEAM 1	RCP		LCP	
Probe	RCP	LCP	RCP	LCP
S_{+1}	------	RCP	LCP	-------
S_{-1}	LCP	------	------	RCP

The results are in agreement with the above theoretical predictions. For example when Beam 1 of the writing beam is RCP and the probe beam is RCP then we observe that the diffracted beam occurs mostly in the -1 direction and the is it polarized LCP. The beam in the +1 direction is less than 2% of that in the -1 direction. When the probe beam is LCP then the light is diffracted into the +1 direction and is RCP. Also as indicated in the table, when the writing geometry or the sample geometry are inverted then the diffraction of the polarized beams is also affected.

The holographic grating is stable as long as the probe beam does not over write the inscribed information. The grating can then be used to measure the circular polarization content of a test light beam. In figure 3 we present the results of the diffraction efficiency into the +1 direction as a function of the PCP content of a test light beam. The intensity of the linearly polarized test beam was constant and rotating a quarter-wave plate varied the polarization state.

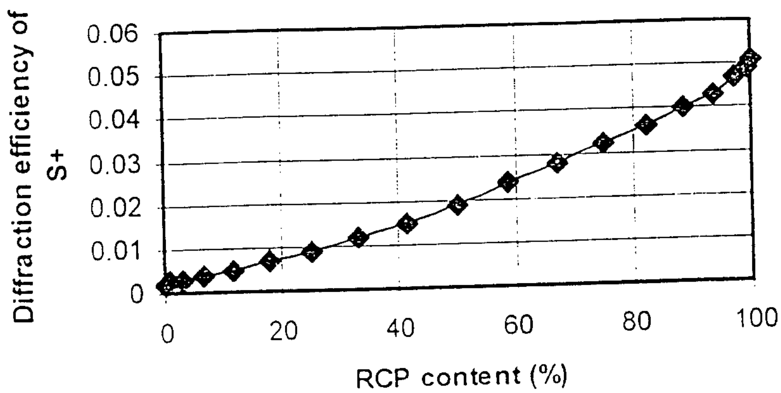

FIGURE 3: Polarization detection of a test beam

The results indicated that the polarization content of the test beam can be measured and that the polymer could be used in device applications. However, the diffraction efficiency was not linear with RCP content as was expected and it is possible that this indicates the although we attempted to prevent a surface relief grating from being formed during the holographic grating writing there may have been a weak grating formed never the less. This would also explain the non-zero value of the diffraction at zero content. This problem may be solve by using a different azo polymer which displays the same level of optically induced birefringence and yet is much less prone to the formation of surface relief gratings. The stability of the holographic grating can also be increased by using higher glass transition temperature polymers and chemical processing such as cross linking.

We have observed that the light diffracted in the −1 and -1 directions are not purely circularly polarized but are elliptically polarized and we believe that this is due to the chromophores which are aligned in the z-direction during the writing process. We are investigating this effect further since this may prove to be a valuable probe for the dynamics of those chromophores during the process of photoinduced birefringence.

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